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Relationship between Intelligence and Executive Functions in Preschoolers

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Связь интеллекта и исполнительных функций у дошкольников

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Abstract. The paper raises the problem of the relationship between executive functions and intelligence in preschool period of the development. Based on the discussion about the components of executive functions proposed by different authors, two components (inhibitory control and working memory) were selected for analysis. Raven Coloured Progressive Matrices were chosen for the assessment of the intelligence. We chose this method due to the fact that there are a lot of preschoolers who have speech problems that prevent an adequate assessment of verbal intelligence. The go/go and go/no-go paradigms to evaluate inhibitory control of Vergunov and Nikolaeva, and a test of Razumnikova and Savinykh aimed at evaluating working memory were used. The specificity of the test aimed at the level of inhibitory control assessment was a fractal structure of the sensory flow. Both go/go and go/no-go series included two identical parts, but children did not know about this. Some children, however, showed better results in the second part of the series rather than the first one. This could indicate that children intuitively discovered the structure of the sensory flow and learned to respond more effectively. In go/go series, children were asked to respond to each presented stimulus (circles of different colors). In the go/no-go series, they were forbidden to respond to a target stimulus (red circles). Calculating the mistakes (reactions to the red circles), we could assess the inhibitory control level. To assess a working memory, the subjects were offered three series including the same set of visual stimuli, and the order of the stimuli was changed in each series. The number of recalling stimuli in each series and interference inhibition resulting from the presentation of the same set of stimuli were calculated. The study involved 90 preschoolers (average age 6.5±0.4 years) of normative development, parents of all children signed informed consents, and all children were told about the goals of the study. It was shown that nonverbal intelligence has no correlation with any parameters of the inhibitory control or parameters of working memory in preschool age. Immaturity of the prefrontal cortex at this age was suggested to be the main reason for the lack of such a link. The low levels of both inhibitory control and interference inhibition could not provide a high level of correlation with intelligence. It was proved that nonverbal intelligence is associated with greater performance in the second part of the go/go series. This suggests that the higher the child's intelligence is, the better they are able to navigate the sensory flow.

Keywords: *go/no-go paradigms; working memory; inhibitory control; interference inhibition*

Аннотация. В статье рассматривается проблема взаимосвязи исполнительных функций и интеллекта. Анализируются компоненты исполнительных функций, предлагаемые разными авторами, выбирается два компонента, включенных практически во все исследования: тормозный контроль и рабочая память. Для оценки интеллекта применяется тест Дж. Равена, направленный на описание невербальной памяти. Такой выбор обусловлен тем, что в дошкольном возрасте еще достаточно много детей, имеющих речевые проблемы, препятствующие адекватной оценке вербального интеллекта. Для оценки тормозного контроля использовались парадигмы go/go и go/no-go Е. Г. Вергунова и Е. И. Николаевой и тест О. М. Разумниковой и М. А. Савиных, направленный на оценку рабочей памяти. Специфика теста, определяющего уровень тормозного контроля, состояла в том, что сенсорный поток, который предлагался ребенку, имел фрактальную структуру и состоял из двух одинаковых частей, о чем ребенку не сообщалось. Некоторые дети тем не менее вторую часть теста выполняли лучше, чем первую. Это могло свидетельствовать о том, что дети интуитивно обнаружили закономерность и научились реагировать эффективнее. В рамках серии go/go у детей вырабатывалась реакция отвечать на каждый предъявляемый стимул. В рамках серии go/no-go запрещалось реагировать на целевой стимул, на который ранее уже была выработана реакция. Предполагалось, что так можно оценить тормозный контроль. При оценке рабочей памяти испытуемым предлагалось три серии, включающие один и тот же набор зрительных стимулов, в каждой серии порядок их предъявления менялся. Оценивались объем воспроизведения материала в каждой серии и интерференционное торможение, возникающее вследствие предъявления одного и того же набора стимулов. В исследовании приняли участие 90 дошкольников (средний возраст 6.5±0.4 года), их всех знакомили с целями исследования. Родители детей подписывали информированное согласие. Было установлено, что в этом возрасте невербальный интеллект не связан ни с параметрами тормозного контроля, ни с параметрами рабочей памяти. В качестве основной причины отсутствия такой связи можно предполагать незрелость префронтальной коры в данном возрасте, что приводит к низким оценкам как тормозного контроля, так и интерференционного торможения. Было показано, что невербальный интеллект связан с большей эффективностью выполнения второй части теста go/go. Это позволяет предположить, что чем выше интеллект ребенка, тем лучше он ориентируется в сенсорном потоке вокруг него.

Ключевые слова: *дети старшего дошкольного возраста; невербальный интеллект; простая и сложная сенсомоторные реакции; рабочая память; тормозный контроль; интерференционное торможение*

Introduction

A. R. Luria was one of the first scientists who studied the role of the frontal lobes (1973). He showed their slow maturation in ontogenesis and significance in behavior (Nikolaeva, 2015). Currently, their functions are associated with executive functions, that is, functions that are responsible for the behavior change managing (Diamond, 2013). Different authors described different contents of executive functions. But most of them agreed that executive function included two components: inhibitory control and working memory (Nikolaeva & Vergunov, 2017). It is the executive functions that ensure the effectiveness of education when a child goes to school. However, when checking a child's school readiness, most psychologists assess the level of the child's intelligence but do not assess the level of executive functions development. Therefore, knowledge of the relationship between intelligence and executive functions could help psychologists to predict child problems that might occur in elementary school more accurately. Despite a lot of research, there is still a significant contradiction regarding the relationship between executive functions and intelligence, especially in preschool age.

Working memory is defined as a higher-order cognitive system, memory, which maintains the necessary information in an accessible form while solving a specific task related to complex cognitive processing (Baddeley, 2007). Inhibitory control is described as an ability to keep irrelevant or misleading information away from interfering with performance, it allows a person to suppress a proponent or automatized response (Bari & Robbins, 2013; Brydges, Reid, Fox, & Anderson, 2012; Luna, 2012; Nigg, 2000). Although inhibiting control appears in infancy (Johnson, 1995), the level of errors associated with controlling functions decreases in childhood and adolescence (Bjorklund & Harnishfeger, 1995; Diamond & Lee, 2011). Studies based on functional magnetic resonance imaging, aimed to analyze the age differences in the activation of the main systems of inhibitory control, have shown that the prefrontal cortex of the brain is responsible for it. However, the specific influence of the prefrontal cortex on the development of inhibitory control is unclear, since the its development is uneven, and the number of errors increases and decreases in different periods of the development (Marsh et al., 2006; Rubia et al., 2006). Moreover, some studies suggest that working memory and inhibitory control can take distinct developmental trajectories (Jurado & Rosselli, 2007). Therefore, each of these components of executive functions may have different types of relations with intelligent parameters.

Preschool age in this context is important because the development of intelligence occurs in a period of immature prefrontal areas of the cerebral cortex, that are responsible for the formation of different inhibitory processes. It is known, that the dorsolateral prefrontal cortex is a necessary region for controlling inhibitory control (Angius, Santarnecchi, Pascual-Leone, & Marcora, 2019); medial prefrontal structures, in turn, are included in frontolimbic and frontoparietal networks, which are necessary to create a connection between intelligence and executive functions (Faul, Fogleman, Mattingly, & Depue, 2019). The immaturity of these structures in preschool age could be reflected in various ways in the relationship between the components of executive functions and intelligence.

Since both intelligence and inhibitory control are formed unevenly, this also leads to different results from different authors. That is why the studies examining the connections between intelligence and executive function in preschoolers (Uka, Gunzenhauser, Larsen, & von Suchodoletz, 2019) have found complex patterns that depend on age. At the age of 4.5 years, children had no connection between inhibitory control and intelligence, this connection appeared in six months, and in the next six months this connection disappeared. This connection with working memory was only 5.5 years later, according to the authors (Uka et al., 2019).

Inhibitory control is considered to be a key component of self-regulation. A huge role in its formation is associated with the processes of brain maturation, as well as environmental influences: first of all, upbringing in the family. Parental self-efficacy is a key parameter of the parental behavior which is related to children's achievements. However, studies of the interaction of parental coregulation, self-efficacy and child's inhibitory control in early childhood are insufficient. Gärtner and co-authors (Gärtner, Vetter, Schäferling, Reuner, & Hertel, 2018) studied to what extent positive and negative parental coregulation and domain-specific and domain-general self-efficacy assessed in the first test (T1) predicted inhibitory control of infants after six weeks (T2). The results are based on data from 90 parent-child dyads (age of children 24–35 months). All indicators of parents were assessed with a questionnaire. Children's inhibitory control was measured using a behavioral inhibition rating scale for executive functions' assessment. According to these data, negative parental coregulation and domain-specific self-efficacy predict infants' inhibitory control. Thus, the child's inhibitory control development is influenced with the conditions of the entire development of the child (including in the womb) and both genetic and epigenetic factors impact on it.

That is why a greater number of works are devoted not to preschoolers, but to older children, who have more certainty in their results due to the greater maturity of their brain networks.

In 96 primary school children, aged 10–13 years, the relationship (Nęcka & Lulewicz, 2016) of intelligence with inhibitory control and working memory were studied. Intelligence was assessed with the Raven Coloured Progressive Matrices. Intelligence was shown to be related to inhibitory control, but was not related to the volume of working memory.

It has also been shown in adults that the function of suppressing undesirable actions is related to the number of extrastriaral D2 receptors (Colzato, van den Wildenberg, & Hommel, 2013), and this relationship is enhanced with the age by increasing the role of inhibitory control (Rozas, Juncos-Rabadán, & González, 2008).

All these results predetermined the task of this study: to identify the relationship between intelligence and inhibitory processes in preschool age.

Materials and Methods

Subjects. The study involved 90 children (50 boys and 40 girls, the age range 6.5±0.4 years) of normative development, attending kindergartens in Saint Petersburg. The parents of all participants gave informed consent, and child participants provided informed assent.

Methods. The go/go and go/no-go paradigm was first proposed by Lappin and Eriksen in 1966, and further developed by G. Logan and colleagues (Logan, Cowan, & Davis, 1984; Logan, 2015). In this version of testing subjects were trained for certain reactions, and then this reaction was forbidden to perform. For this purpose, the ReBOS method (reflexometry with biofeedback) was used (Vergunov & Nikolaeva, 2009). The technique consists of 3 series: training, simple (go/go) and complex (go/no-go) sensorimotor reactions. The training session is conducted so that the experimenter can determine how well the subject understood the instructions and correctly performed the task. Circles of different colors were shown to the children on the computer at the same interval. According to the instruction, one had to press the enter key as quickly as possible when the circle appeared. In the go / go series, as in the training series, the participant was asked to react to all stimuli (circles of different colors) that are presented on the screen, and press the enter key when they appeared on the screen. Unlike the training series, in which stimuli were presented at the same interval, in this series the structure of the stimuli flow was a fractal one. In the go/no-go series, the subject was required not to react to a key stimulus (not to press the enter key when red circles appeared on the screen), whereas the subject must respond to all other stimuli. The last series was the assessment of the quality of inhibitory control: the subject had to suppress the desire to perform the previously learned actions.

It is worth noting that the peculiarity of this version of the test is that the signals flow consists of two identical parts. However, the subjects are unaware of this. Some children guess about this, because they do the second part of series better than the first one.

We calculated the time of simple and complex sensorimotor reactions, the number of missed stimuli, and the number of errors (reactions to a forbidden signals).

To estimate the volume of working memory and interference processes in it, an original computerized method was used (Razumnikova & Savinich, 2016). Subjects were offered three series included the same set of visual stimuli, and the order of the stimuli was changed in each series. The total number of the presented objects was 30 pieces. At the first presentation, the subject saw three objects and according to the instructions had to "mark the object with the mouse cursor that was not marked earlier." Then new objects were added to the objects already seen, and the time for selecting a new object was not regulated. As soon as the subject made a mistake, that is, clicked on an object that he had already selected earlier, a new series with the same instruction began. In each series, the same objects were presented, but in a different sequence and in different combinations, which created a basis for interference of the already presented information and new one. The number of correctly recalled objects in each of the three series was recorded, as well as interference, i. e. overlapping of one information with another. In this case, the number of correctly reproduced stimuli in the second and third series was subtracted from the number of correctly reproduced objects in the first series, and the number of correctly reproduced objects in the third series was subtracted from the number of correctly reproduced objects in the second series.

Interference also represents inhibitory processes in working memory, since the reproduced information in one series prevents it from being reproduced in another series due to the proximity of the presented objects (Razumnikova & Nikolaeva, 2019).

The intelligence was assessed with Raven Coloured Progressive Matrices (Raven J. C., Court, & Raven J., 1984). Children were asked to identify the piece required to complete a figural pattern from six variances. This test uses a multiple-choice response and children have to identify the missing component in figural patterns out of six alternatives. The test consists of 36 figural patterns, divided into three series (A, AB, C), each series, in turn, consists of 12 tasks (Raven J. C. et al., 1984). The total score represents the total number of correct responses.

Matrices allow us to evaluate the process of making a logical decision in such conditions that the decision is associated with choosing the best option in the shortest possible time. The results obtained are not determined by the erudition of the subjects and do not depend on their level of education. The result depends only on the ability to logical analysis, spatial imagination, and the features of a person's holistic perception of the image.

When performing test tasks, a person activates the processes of perception, attention and imaginative thinking. Performing the color matrix test requires maximum concentration and attention, since reducing these indicators will inevitably lead to errors. All this assumes the importance of inhibitory control for the quality of the test. In series A, the task is to supplement the main image with one of the following fragments that match the specific image. Successful completion of the task requires a thorough analysis of the components of the main image and the detection of similar details in one of several fragments.

Tasks in series B are based on the principle of finding similarity in pairs of figures. It is necessary to understand the principle according to which the figure is constructed and select the missing fragment. The definition of the axis of symmetry is essential, according to it the main sample contains the figures. The test was conducted individually.

Regression analysis was performed to assess the impact of the variables studied with using the SPSS-22 program. All tests were two-tailed and were analyzed using a set level of significance of $p \leq .05$. The data was first checked for outliers, normality of variables, and for violations of statistical assumptions of Linear Regression Models.

Results

Table 1 shows data of the level of nonverbal intelligence and the volume of working memory in three recalls. The data shows that the level of intelligence of preschool children is within the age norm. The first recalling is the best one and then mechanism of interference inhibition begins work. There are no any significant differences due to the high standard deviations.

Table 1

The level of nonverbal intelligence (scores) and working memory (numbers of objects) in preschoolers (means and standard deviations)

Intelligence	Working memory		
	*V*1	*V*2	*V*3
21.2±5.4	16.0±7.3	10.1±6.0	10.4±5.2

*Note. V*1, *V*2 and *V*3 — the first, second and third recalls respectively.

Table 2 shows the results of the go/go series in which the child had to react to all the stimuli presented on the computer screen. We have already said that the second part of the test repeats the first one. A fairly large variance of responses indicates that a small number of children still guessed the structure of the presented flow, and most of the children were simply tired by the end of the series.

Table 2

The results of the first and second parts of the go/go series (means and standard deviations)

Part 1		Part 2	
Time of reaction (ms)	Missing reactions	Time of reaction (ms)	Missing reactions
394.3±77.3	4.4±3.4	420.7±71.3	5.6±3.8

In *Table 3* there are the information about the go/no-go series. Since the inhibitory control at this age was not yet formed, you can see that both the reaction time to the stimulus and the number of skips increases. The reaction time was increased significantly in comparison ($p \leq .05$, t-test criterion) with the reaction time in the previous series. At the same time, children make quite a big number of erroneous reactions. At the same time, it is worth noting the high degree of deviations in the number of errors and omissions, which indicates that inhibitory controls have different developmental levels in children.

Table 3

The results of the first and second parts of the go/no-go series (means and standard deviations)

Part 1			Part 2		
Time of reaction (ms)	Missing reactions	Mistakes	Time of reaction (ms)	Missing reactions	Mistakes
552.4±78.5	9.2±6.3	9.0±4.2	563.6±85.9	8.6±5.7	9.0±4.5

A *linear regression analysis* of the influence of the independent variable IQ (Intelligence) on all the studied parameters was performed. The results are presented in *Table 4*.

Table 4

Influence of the independent variable IQ on go/go reaction parameters

Dependent variables	R^2	β	p
Reaction time in the second part of the go/go reactions	.056	−.237	.024
Omissions in the second part of the go/go reactions	.057	−.238	.023

Table 4 shows that the higher the child's level of the intelligence is, the faster he (she) reacts to the appearance of a stimulus in the second part of a simple sensorimotor reaction, and the fewer stimuli are missed in the second part of the go/go series. It is worth remembering that the signal flow in this version of the study consists of two identical parts. This result of the regression analysis indicates that the higher the child's intelligence is, the more likely he (she) guesses that the second part of the test repeats the first one.

There were no relations between intelligence and go/no-go reaction parameters. It is important to note that the regression analysis did not reveal a connection between intelligence and all the parameters of working memory under study.

Discussion

The study tested the hypothesis of the relationship of intelligence with the parameters of the executive functions. To test intelligence, we used Raven Coloured progressive matrices, whereas in the literature we can find an assessment using this test as well as the D. Wechsler test. It is obvious that both intelligence and executive functions are not a single process, but each of them includes many components. Executive functions and intelligence refer to similar processes and there is a discussion to which extent they are tied to each other (Duggan & Garcia-Barrera, 2014).

Our data shows that intelligence relates to the ability of a child to navigate a sensory flow, but is not consistent with research arguing that intelligence is related to inhibitory mechanisms (Ardila, Pineda, & Rosselli, 2000; Pascual-Leone, Amedi, Fregni, & Merabet, 2005; Roca et al., 2010; Salthouse, Atkinson, & Berish, 2003). Our data does not agree with studies that claim a close relationship between working memory and interference control with intelligence. Moreover, Blair (2006) concludes that intelligence, executive functions and working memory form a unitary construct. It is worth emphasizing that all researchers talk about very moderate relations between components, it does not allow them to be attributed to a single phenomenon (Anderson, 2006; Tillman, Bohlin, Sörensen, & Lundervold, 2009).

We believe that the lack of a connection between intelligence and the parameters of executive functions is associated with the age of subjects in whom the structures responsible for these processes have not yet matured.

The condition for connecting executive functions with intelligence may be their general dependence on social and demographic family factors. The fact that memory changes significantly depending on the child's living conditions in the family is shown in the work of a large team of authors (Belolutskaya et al.., 2018). It was found that the quality of working memory depends on sensorimotor integration (Cowan, Li, Glass, & Scott, 2018), speech and mathematical abilities (Atkinson, Waterman, & Allen, 2019; Chamandar, Jabbari, Poorghorban, Sarvestani, & Amini, 2019; Gunzenhauser, Saalbach, & von Suchodoletz, 2017). Moreover, it changes significantly with age (Razumnikova & Nikolaeva, 2019), and age-related changes depend on morphological changes, in particular, in the early school age (7–10 years old), when a considerable role is played by the corpus callosum, and later by the thickness of the occipital-temporal cortex (Bathelt, Gathercole, Johnson, & Astle, 2018). It is obvious that at preschool age the child is more influenced by the conditions of stay in the family (Nikolaeva, 2017). Previously, it was shown that the older the father at child's birth is and the higher the mother's education is, the higher intelligence the child has. And with a lower order of child's birth and number of children in the family the child intelligence is higher (Nikolaeva, Goncharov, & Borisenkova, 2017). This data could be explained by the fact that the older the father, the more likely it is that the mother will eat better during pregnancy, she will have a more prosperous family environment, because typically with age a person has a larger salary. If the mother has a higher education, it is likely that she values the education, which means that she will pay more attention to the development of cognitive processes in the child (Engle & Kane, 2004). The more children in the family, the less attention is paid to each of them, although intelligence is determined by communication with adults, but not with peers. And, of course, in a typical family, more attention is paid to the first child, because for a while he (she) is the only child in the family.

In terms of working memory and inhibitory control, things may not be as straightforward. It is known that the genetic component is generally more important for memory (Cowan et al., 2018), although the significance of the social and demographic components of influence may also be great (Ekerim-Akbulut, & Selcuk, 2018).

No less significant is the study of the influence of family factors on the formation of inhibitory control. In a large group of German children (263 people), no family factors were found to predict the development of inhibitory control (Gunzenhauser et al., 2017). However, there are works that have found a link between inhibitory control and particular experience of a child in the family (Roell, Viarouge, Houdé, & Borst, 2017; Santillán & Khurana, 2018). All these results need further research, that would include more parameters of both executive functions and working memory.

Conclusions

The current study is aimed to identify the relationship between preschool-age children's executive functions (working memory and inhibitory control) and intelligence. It was shown that a close relationship was found only between intelligence and the child's ability to navigate the sensory flow. No associations were found between intelligence, inhibitory control, and working memory parameters. A possible explanation is the immaturity of the prefrontal cortex at this stage of ontogenesis, which is responsible for both inhibitory control, working memory and intelligence.

Ethical Approval

All procedures performed in studies involving human participants were in accordance with the ethical standards of the Institutional and/or National Research Committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards.

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Limitation

This study has a considerably big sample to conduct statistical analysis and get meaningful results. However, it is possible that the description of family circumstances and their inclusion in the results would reveal the influence of family on all the parameters under study. It would explain the high standard deviations in the number of errors in the series not only by the slow maturation of the prefrontal cortex, but also by the specifics of intra-family relationships.

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